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MANGANIN GAGE PRESSURE MEASUREMENTS UNDER CONDITIONS WHERE GAGE DEFORMATION OCCURS

John J. Trimble

July 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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It is sometimes desirable to use manganin piezo-resistive pressure gages under conditions where gage deformation occurs. In such circumstances, the pressure can be measured only if the strain on the gage is measured independently and if the strain coefficient of the gage is known. We have experimentally determined the strain coefficient of manganin gages as a function of strain at a range of pressures and strain rates. For small strains (less than 0.1 percent), the strain coefficient is about 0.67. As strain occurs, the strain coefficient increases to a value of about 2. In cantilever beam

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20. ABSTRACT (Continued)

tests, with no pressure on the gage, the transition occurs slowly, and the strain coefficient reaches the value of 2 at about 2 percent strain. In a test where pressure and strain are applied simultaneously, the transition is more rapid and the strain coefficient attains a value of about 1.8 at 0.5 percent strain.

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I. INTRODUCTION

In a recent experiment at Ballistic Research Laboratory (BRL), a need developed for a transducer to measure pressure in confined explosive charges which were reacting in a non-detonative fashion. The transducers were to be mounted internally in contact with the explosive and be able to measure pressures from .2 to 1.0 GPa with rise times of 100 to 300 μsec. In addition, the gages were required to monitor the pressure profile during case expansion.

A manganin piezo-resistive foil gage was selected to monitor the pressure pulse. Manganin is a copper-manganese-nickel alloy whose resistance has a high sensitivity to pressure changes. Manganin gages have been used extensively in the past to measure pressures in planar shock waves and in static situations where the gage cannot deform. Wackerle[1], among others, has described techniques for using manganin gages. Typically, the gage consists of a thin foil grid with a thickness of about 0.013 mm, a length and width of 3 to 6 mm, and a resistance of about 50 ohms. Various calibrations (see Reference 1) have shown that the resistance of the gage increases in a nearly linear fashion with pressure; i.e.,

$$\frac{\Delta R}{R} = CP$$

where R is the gage resistance, ΔR is the increase in resistance caused by pressure,C is called the gage coefficient, and P is Pressure in GPa, C is approximately 0.023 ohms/ohm/GPa for static pressures and approximately 0.027 ohms/ohm/GPa for shock waves.

In our experiments, deformation of the gage frequently occurs and the resistance of the gage is affected by strain as well as pressure. If the strain on the manganin gage is measured independently and if the dependence of resistance on strain is known, then the pressure can be determined. Rosenberg[2] suggested using a constantan gage in conjunction with a manganin gage. The resistance of constantan is nearly independent of pressure, and the gage measures strain only. If the two gages are mounted so that each sees the same strain, the pressure can be determined as long as the strain coefficient of manganin is known.

The resistance of a foil element varies with strain as follows:

$$\frac{\Delta R}{R} = K \frac{\Delta L}{L}$$

---

[1] *Wackerle, J., Johnson, J. O., and Halleck, P. M., "Projectile Velocity Measurements and Quartz and Manganin Gage Pressure Determinations in Gas Gun Experiments," LASL 5844, 1975*

[2] *Rosenberg, J., "Development of a Piezo-Resistant Transduce to Measure Stress-Time Output of Small Detonators," Report by Stanford Research Institute to Picatinny Arsenal Contract DAAA21-71-C-0845*

where K is strain coefficient and L is the length of the gage. Unfortunately, the strain coefficient of manganin appears to depend on the conditions under which the measurement is made. It has been reported in the past[3], that manganin has a strain coefficient of 0.47 under static conditions at atmospheric pressure, but Charest[4] determined a strain coefficient of 2.0 for manganin under shock conditions. In order to use Rosenberg's technique, we had to determine how the strain coefficient of manganin varies with stress and strain. In this report, we describe an experimental effort to accomplish this objective.

II. DESCRIPTION OF EXPERIMENT

A. Test Setup.

To determine the strain sensitivity of a manganin gage at low strain rates and atmospheric pressure, a manganin and a constantan gage (3.2 mm on a side) were mounted on a cantilever beam and the beam was deflected at varying rates. A sketch of the arrangements is shown in Figure 1. Experiments at higher strain rates and pressures were conducted using the apparatus in Figure 2. Pressure is applied to the small piston (19 mm in diameter) from a larger piston which is driven by burning gun powder in a large chamber. This arrangement provides a pressure amplification of 16 times which results in pressures as high as 0.5 GPa on the gages. A dual manganin/constantan gage, Figure 3, is cemented to the bottom of a 3.2 mm thick steel plate. As the piston moves in, the steel plate strains and applies pressure to all gages. Pressure is transferred to the bottom gage on the anvil by cerrobend, a soft, high density material similiar to Wood's metal. The cerrobend was generally, but not always, precompressed in order to obtain higher pressure at the same value of strain. The anvil gage does not deform, and the change in its resistance provides an accurate measure of pressure. The pressure on the anvil gage is assumed to be the same as on the dual gage and the strain on the manganin portion of the dual gage is assumed to be the same as on the constantan portion. The strain coefficient is determined from the following equation:

$$K = 2 \left[\left(\frac{\Delta R}{R} \right)_m - \left(\frac{\Delta R}{R} \right)_{mp} \right] \Big/ \left(\frac{\Delta R}{R} \right)_C$$

where R is the resistance on the gage and the subscripts m, mp, and C stand for the manganin anvil gage, the manganin portion of the dual gage,

---

[3] *deForest, A. V., "As reported in Strain Gage Techniques," Murray and Stein, Mass Institute Technology, 1962*

[4] *Charest, J., Dynasen, Inc., "As reported in Strain-Compensated Stress Gage Development," Lookheed Missiles and Space Co., LNSC-D506298*

CANTILEVER BEAM

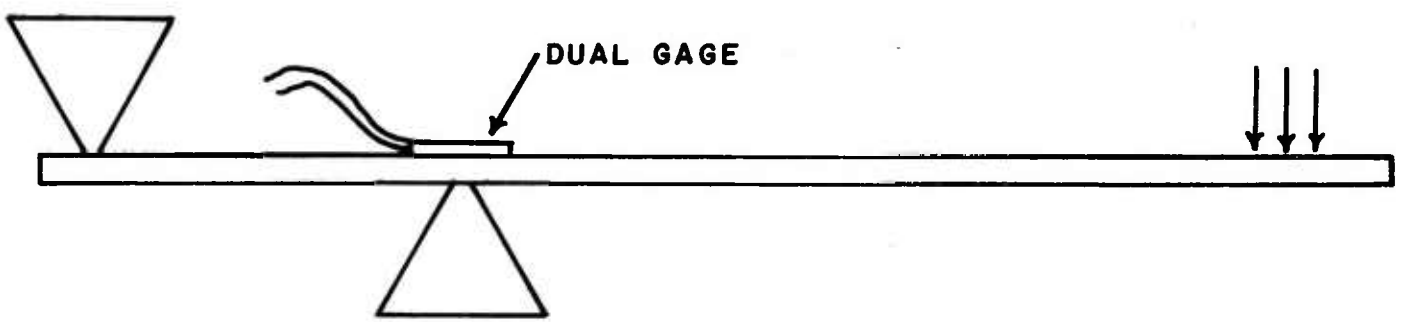

Figure 1. Sketch of Apparatus Used in Cantilever Beam Tests

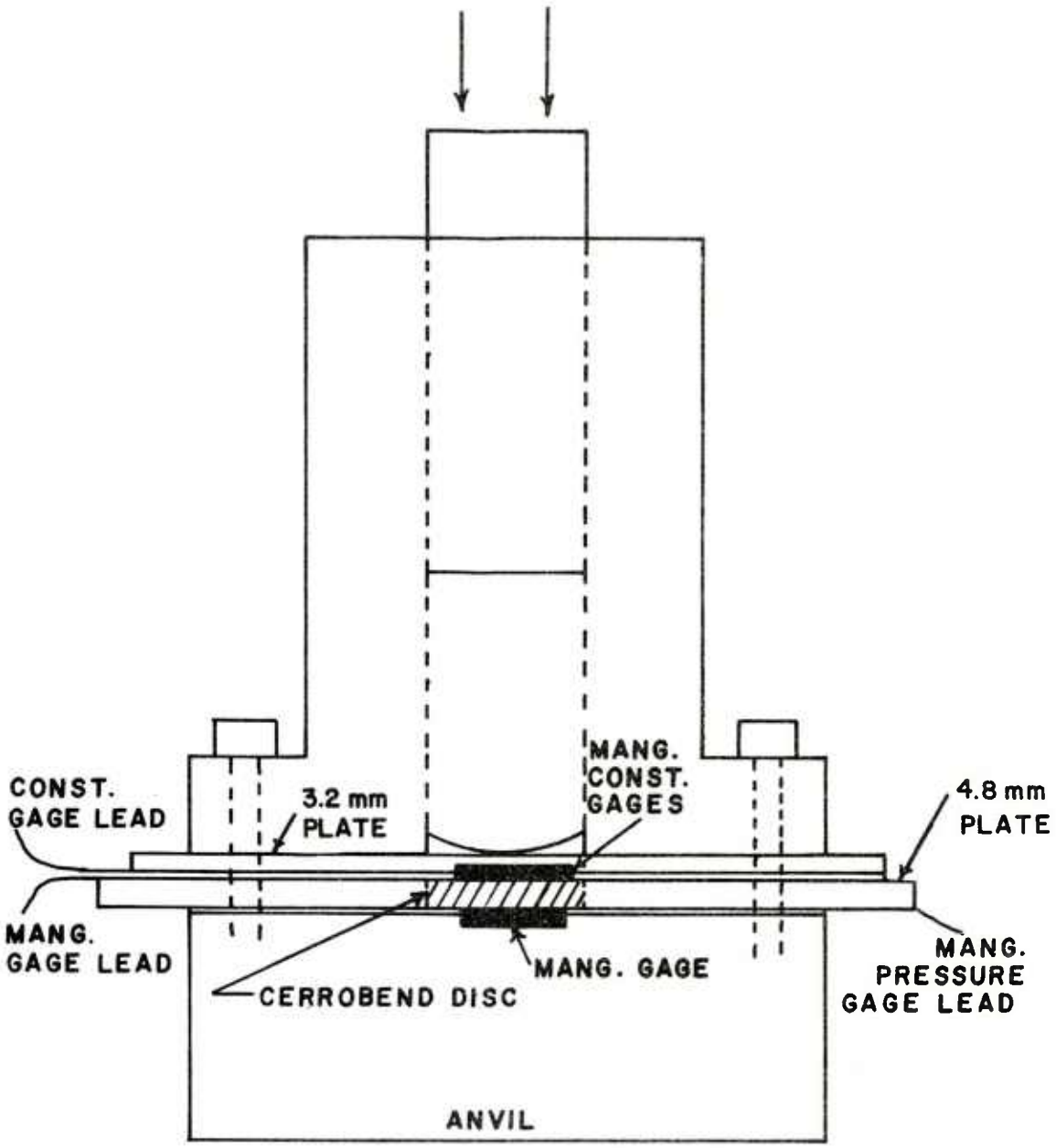

Figure 2. Apparatus Used to Apply Stress and Strain Simultaneously to a Manganin Gage

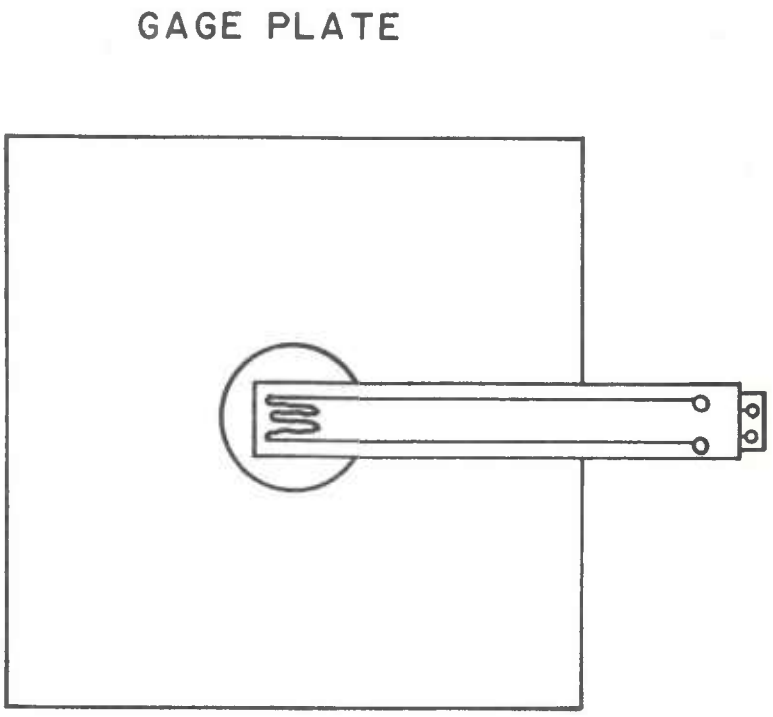

Figure 3. Position of Gage on Gage Plate

and the constantan portion of the dual gage. To vary strain rates, four different pistons were utilized, having radii of curvature of 9.5, 16, 19, and 22 mm on the bottom end.

B. Data Acquisition System.

In order to produce high level signals from our pressure and strain gages, pulsed power supplies (K-Line KCGS-2HV) were utilized. By pulsing the gages, it is possible to run them at higher current levels and consequently obtain higher signal-to-noise ratios. The active gage was used in one arm of a four-arm bridge circuit which was pulsed with 75 volts for a duration of 12.0 milliseconds. During this time, pressure and strain were applied. To minimize the effects of gage heating, the other three arms consisted of inactive gages.

The other components in our system included three signal conditioning amplifiers (Tektronix A502), a wide-band tape recorder (Honeywell Model 96), and a fibre-optics oscillograph recorder (Honeywell Model 1858) Figure 4.

III. RESULTS

The results of two cantilever beam tests are shown in Figures 5 to 8. For each shot, the figures give the strain coefficient as a function of strain and time and the strain as a function of time.

Results of three activator shots with precompressed cerrobend are shown in Figures 9 to 14. Each shot had a different radius of curvature, and these are identified in the figure captions. The figures show the strain coefficient as a function of strain, pressure as a function of strain, and strain as a function of time. Figures 15 and 16 show the same data for a shot with a 22 mm radius of curvature and unprecompressed cerrobend. This permitted considerable strain to occur at low pressure. Figures 17 and 18 give results from a shot with 3.2 mm gages and a 19 mm radius of curvature.

IV. DISCUSSION

For small strains, all of our tests show that the strain coefficient for manganin is about .67 as opposed to the .47 value which has been reported (See Reference 3). The manufacturer of our gages, Micro-Measurements, Inc., has confirmed the higher value. Above 0.1 percent strain, the strain factor gradually increases to a value between 1.8 and 2.0. The value of 2 is expected for a material in the plastic state which maintains constant volume and resistivity as it deforms. This can be seen from the following argument. The change in resistance with length is determined from:

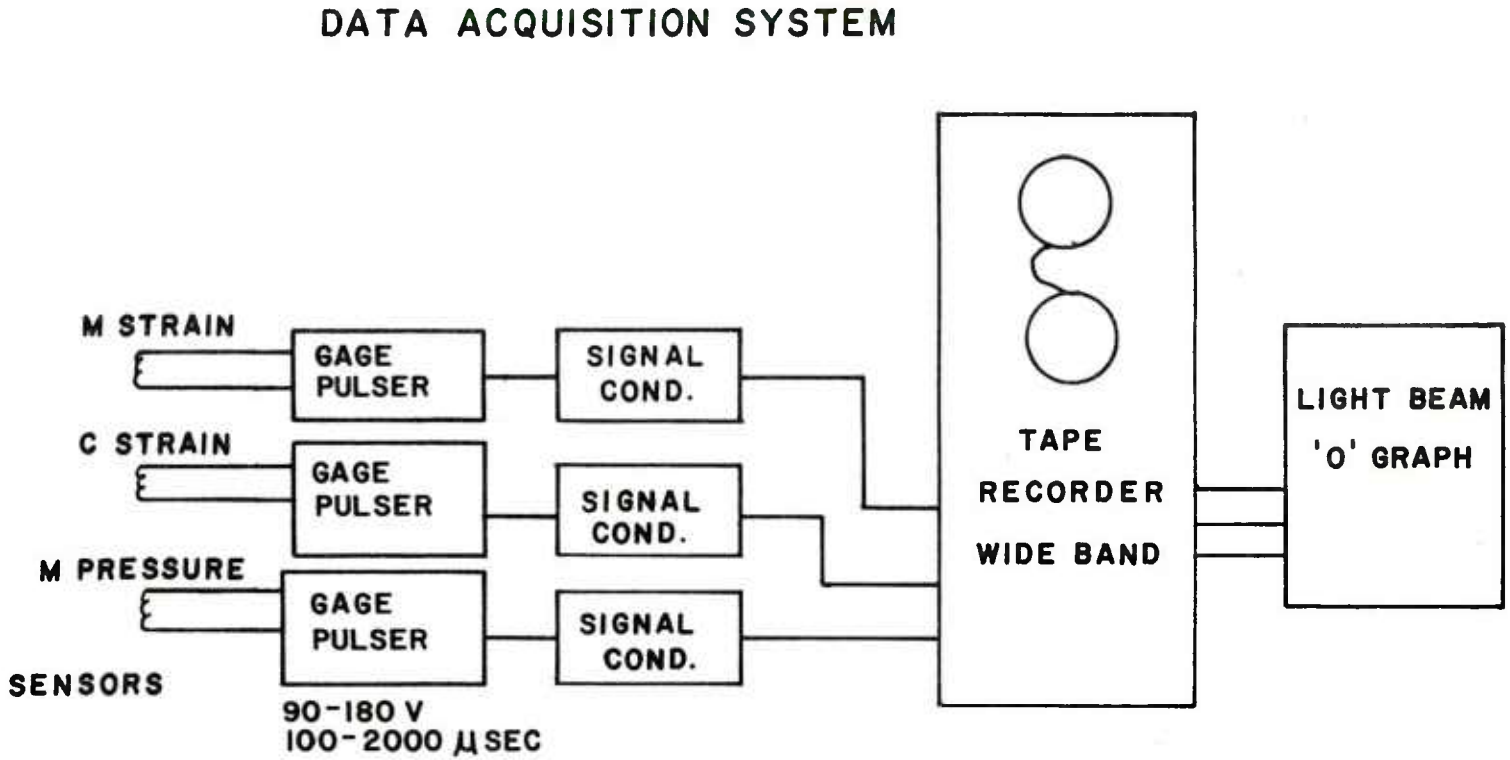

Figure 4. Data Acquisition System

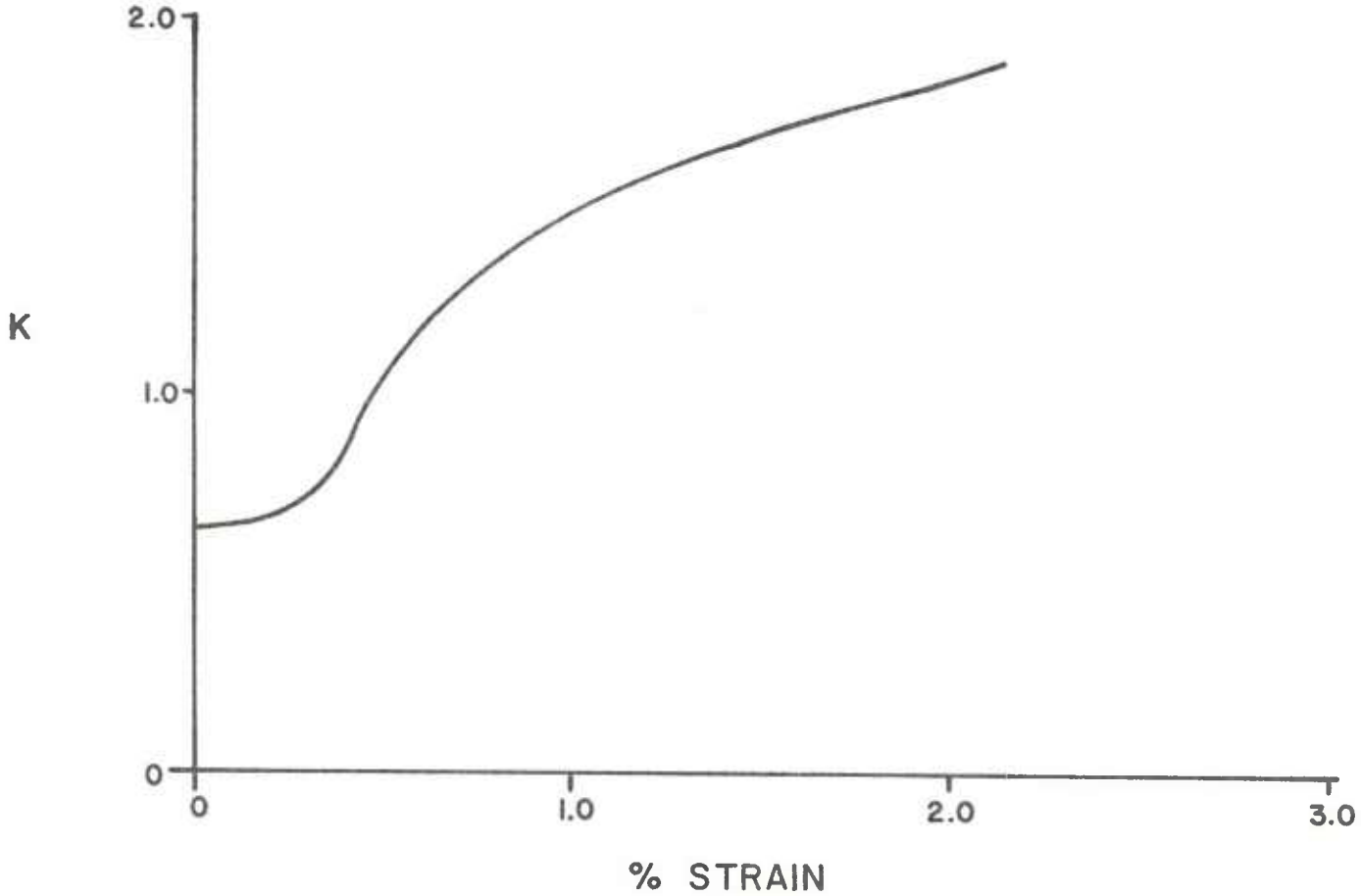

Figure 5. Strain Coefficient (K) of a Manganin Gage as a Function of Strain as Determined in a Cantilever Beam Test

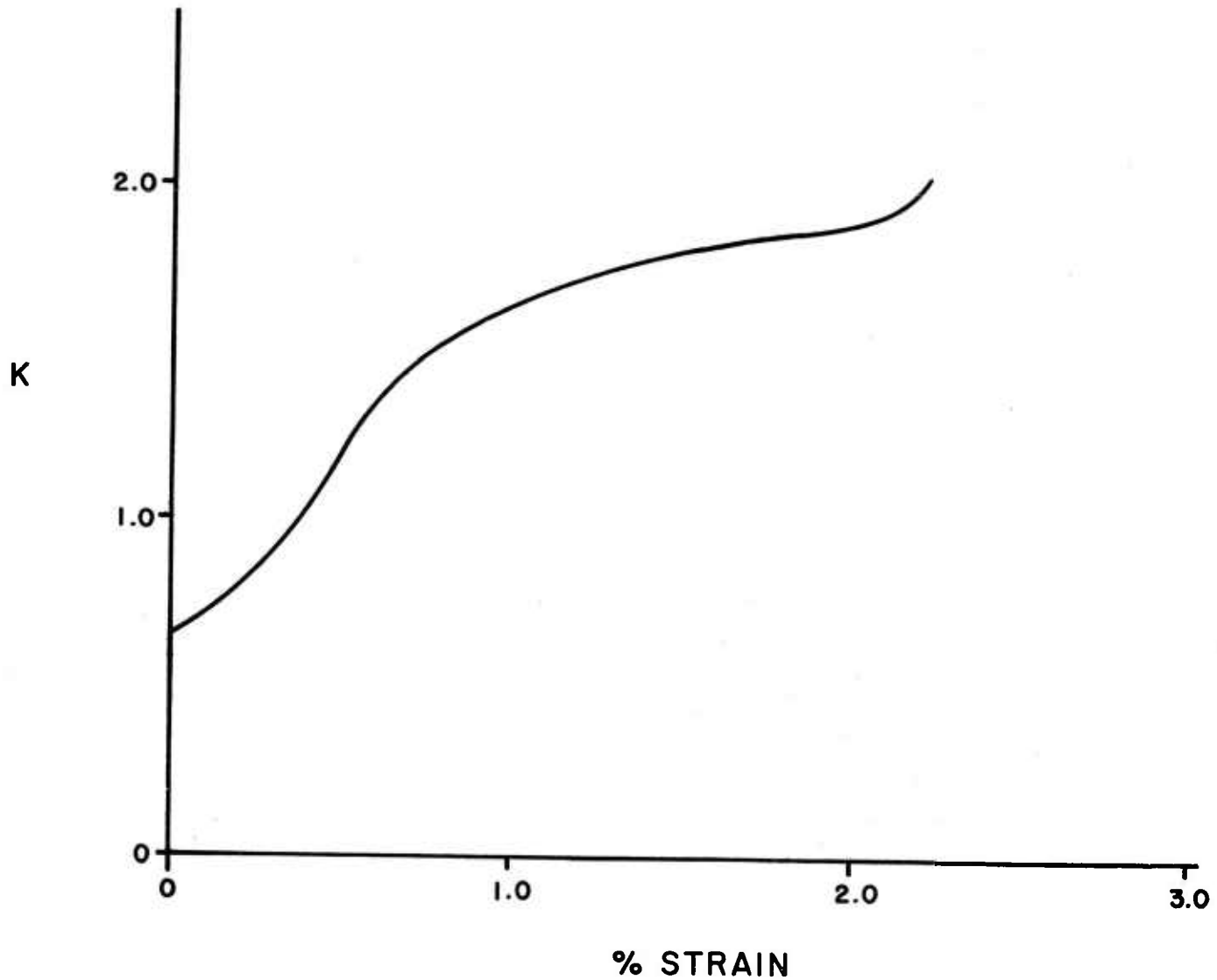

Figure 6. Strain Coefficient (K) of a Manganin Gage as a Function of Strain as Determined in a Cantilever Beam Test

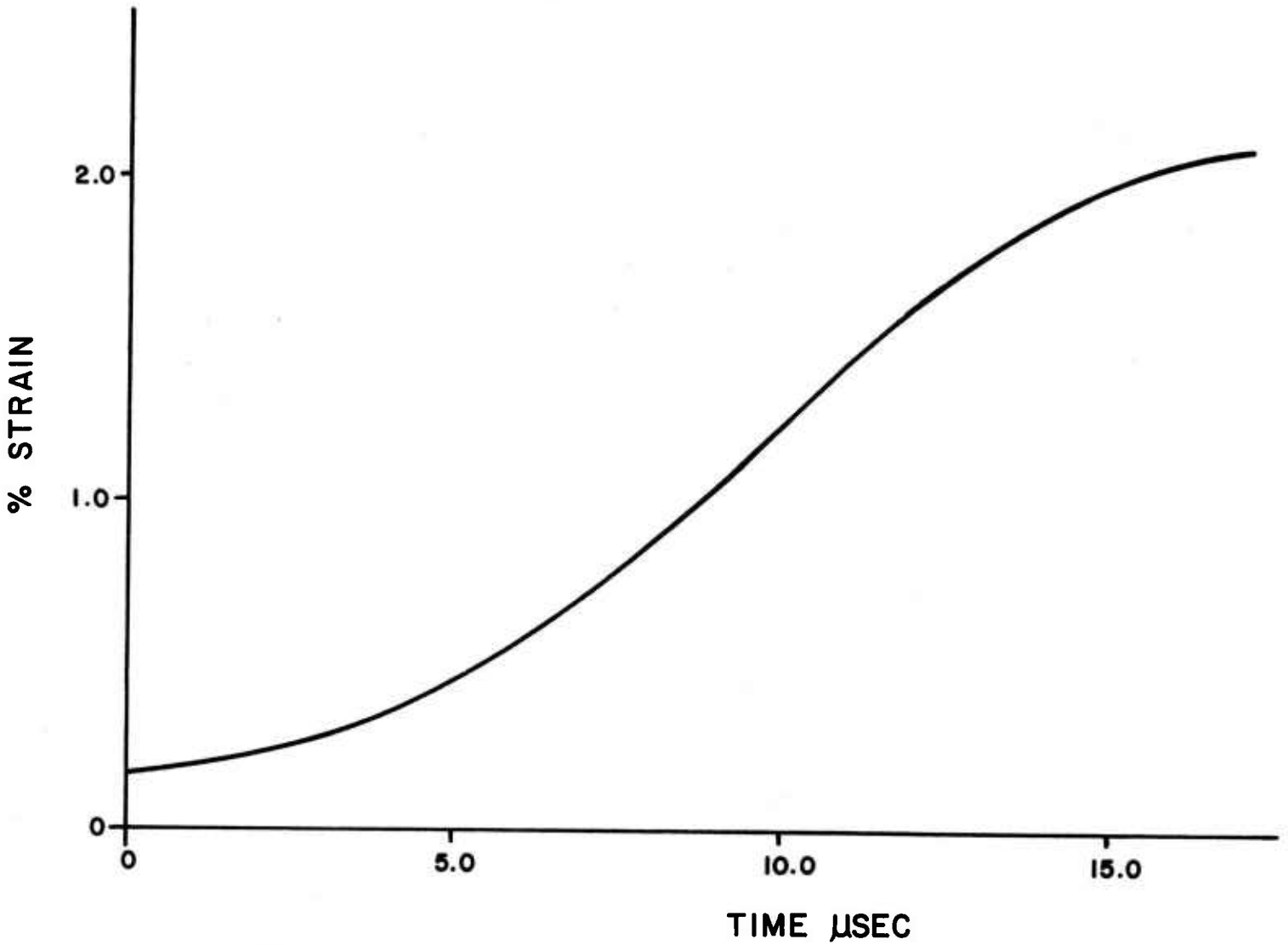

Figure 7. Strain as a Function of Time for the Test Depicted in Figure 5

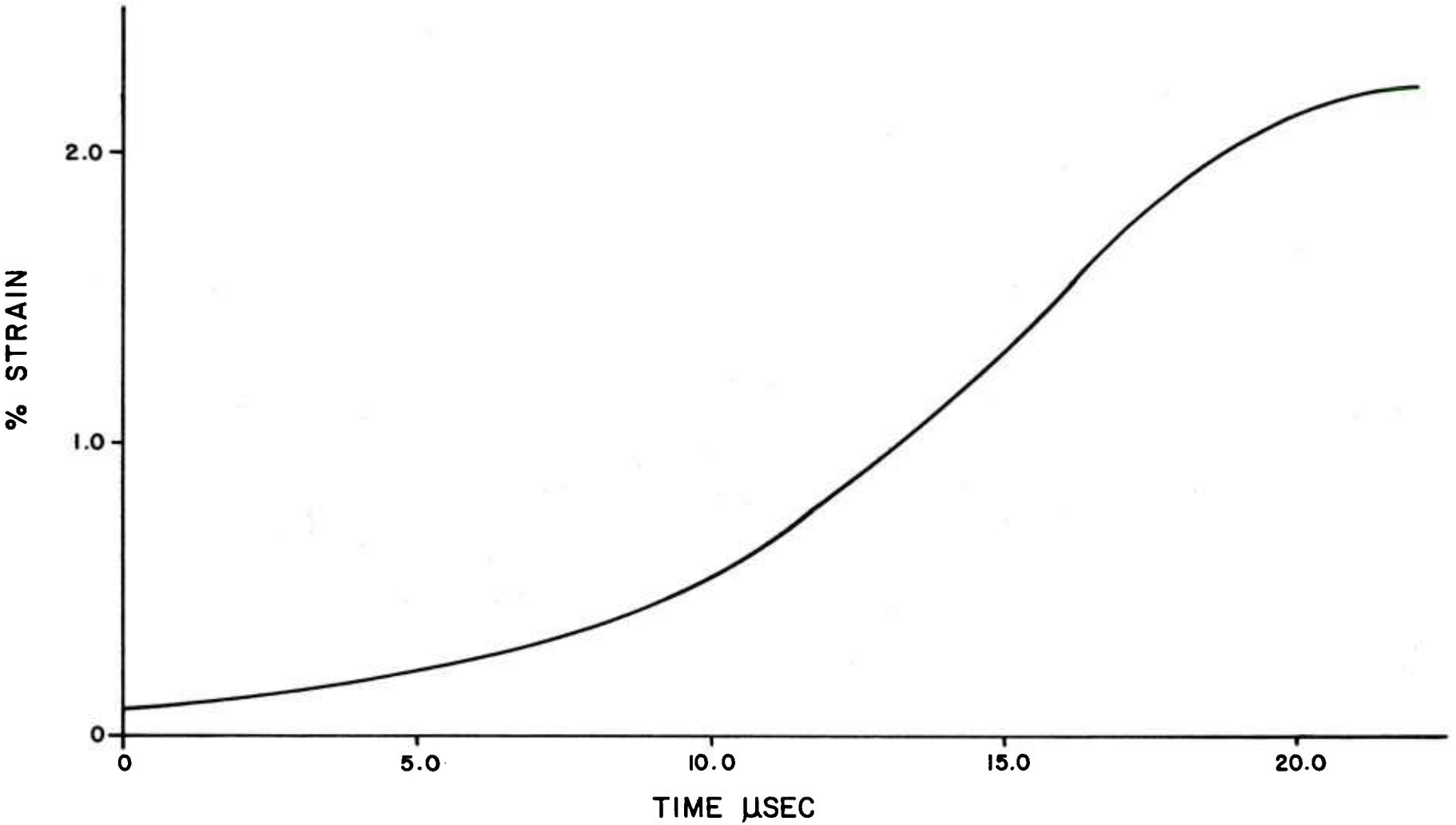

Figure 8. Strain as a Function of Time for the Test Depicted in Figure 6

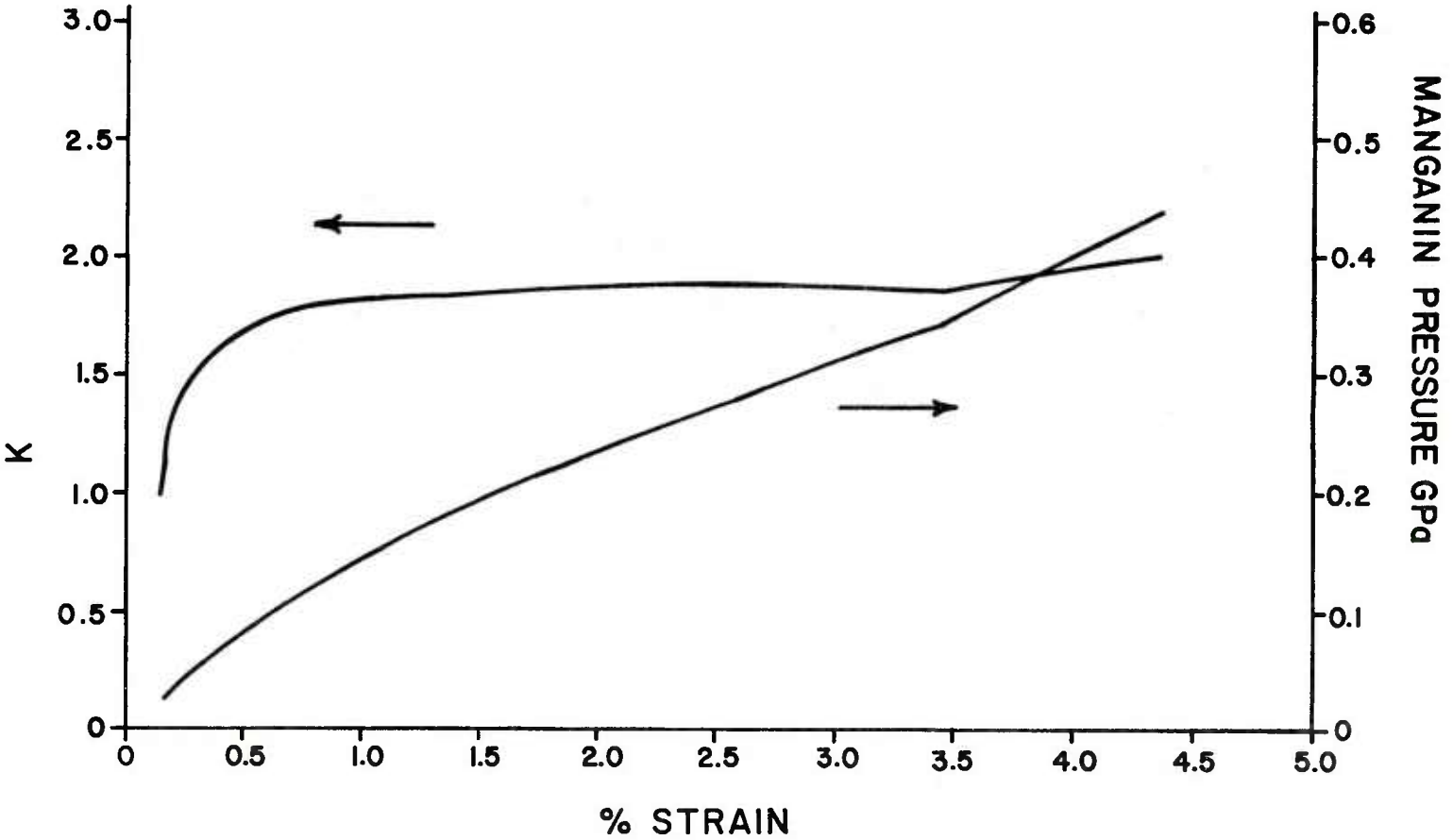

Figure 9. Strain Coefficient (K) of a Manganin Gage as a Function of Strain as Determined in an Activator Test Using a Piston with a 16 mm Radius of Curvature. Pressure versus strain is shown on the right hand scale.

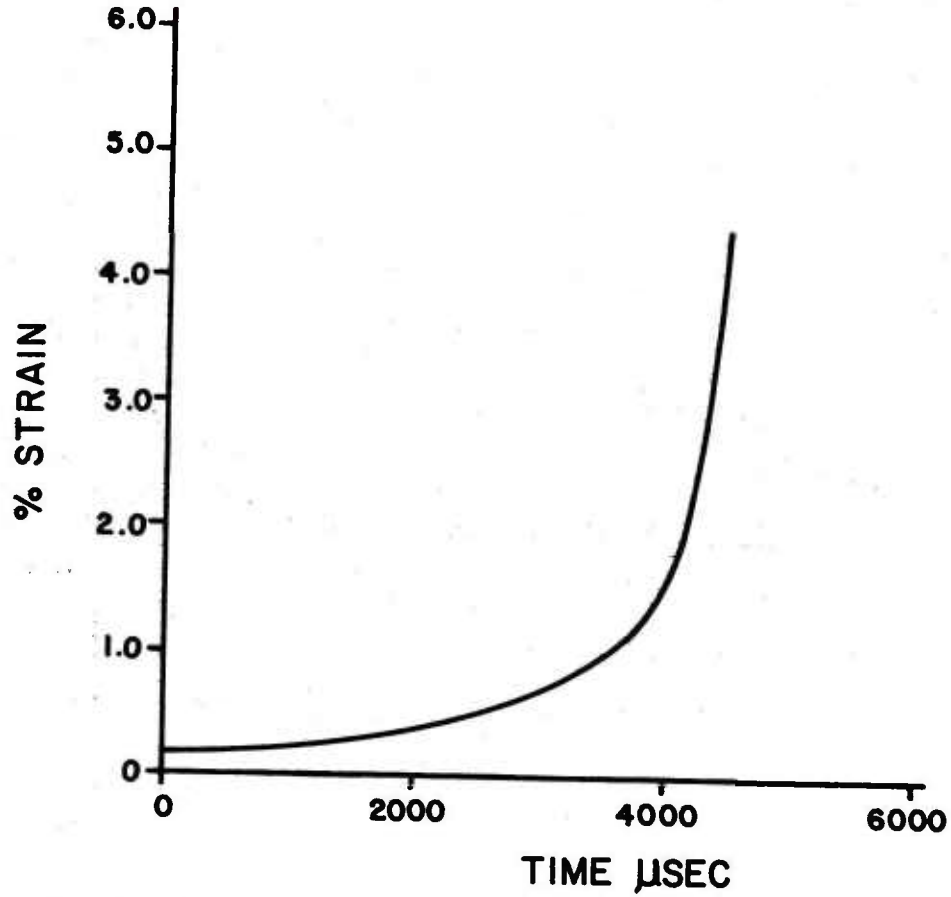

Figure 10. Strain as a Function of Time for the Test Depicted in Figure 9

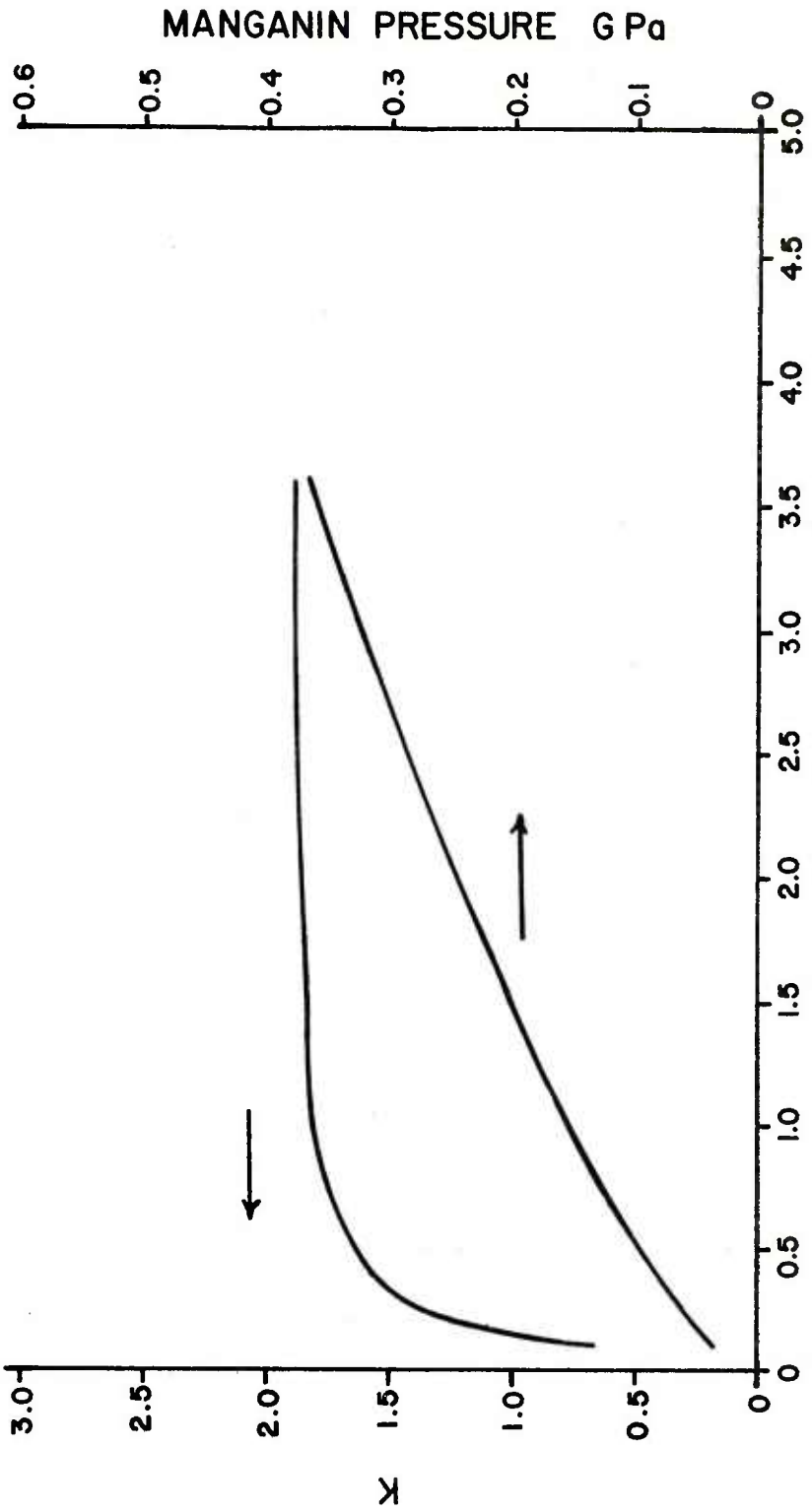

Figure 11. Strain Coefficient (K) of a Manganin Gage as a Function of Strain as Determined in an Activator Test Using a Piston with a 19 mm Radius of Curvature. Pressure versus time is shown on the right hand scale.

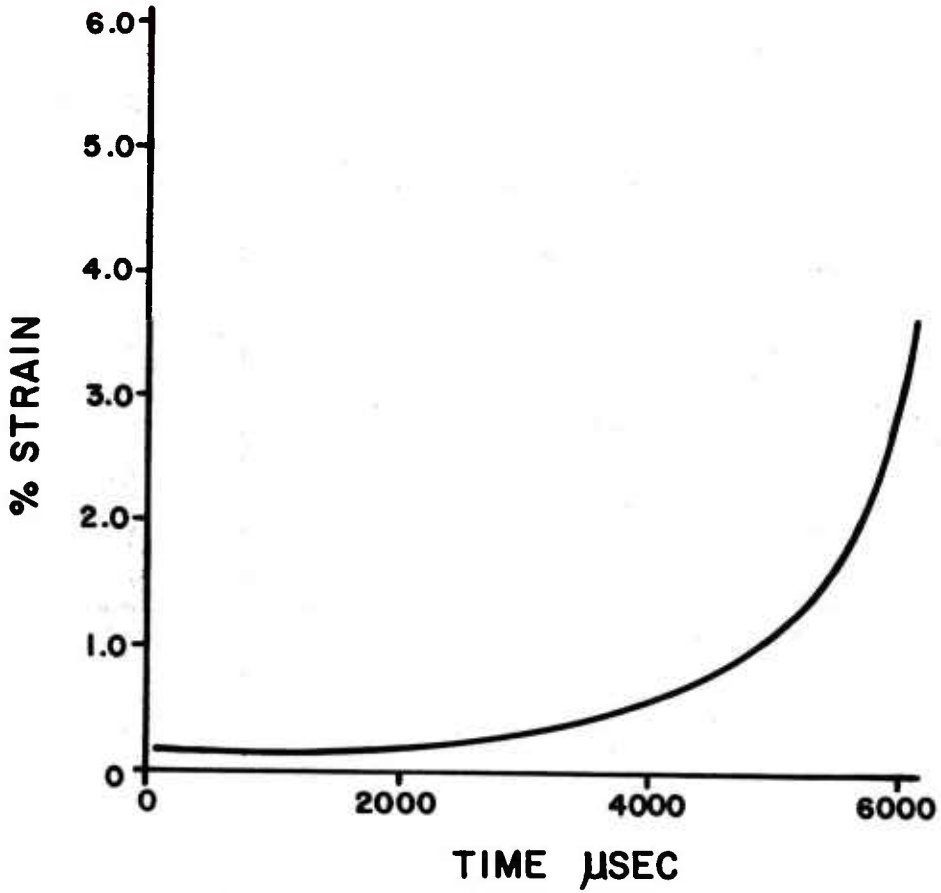

Figure 12. Strain as a Function of Time for the Test Depicted in Figure 11.

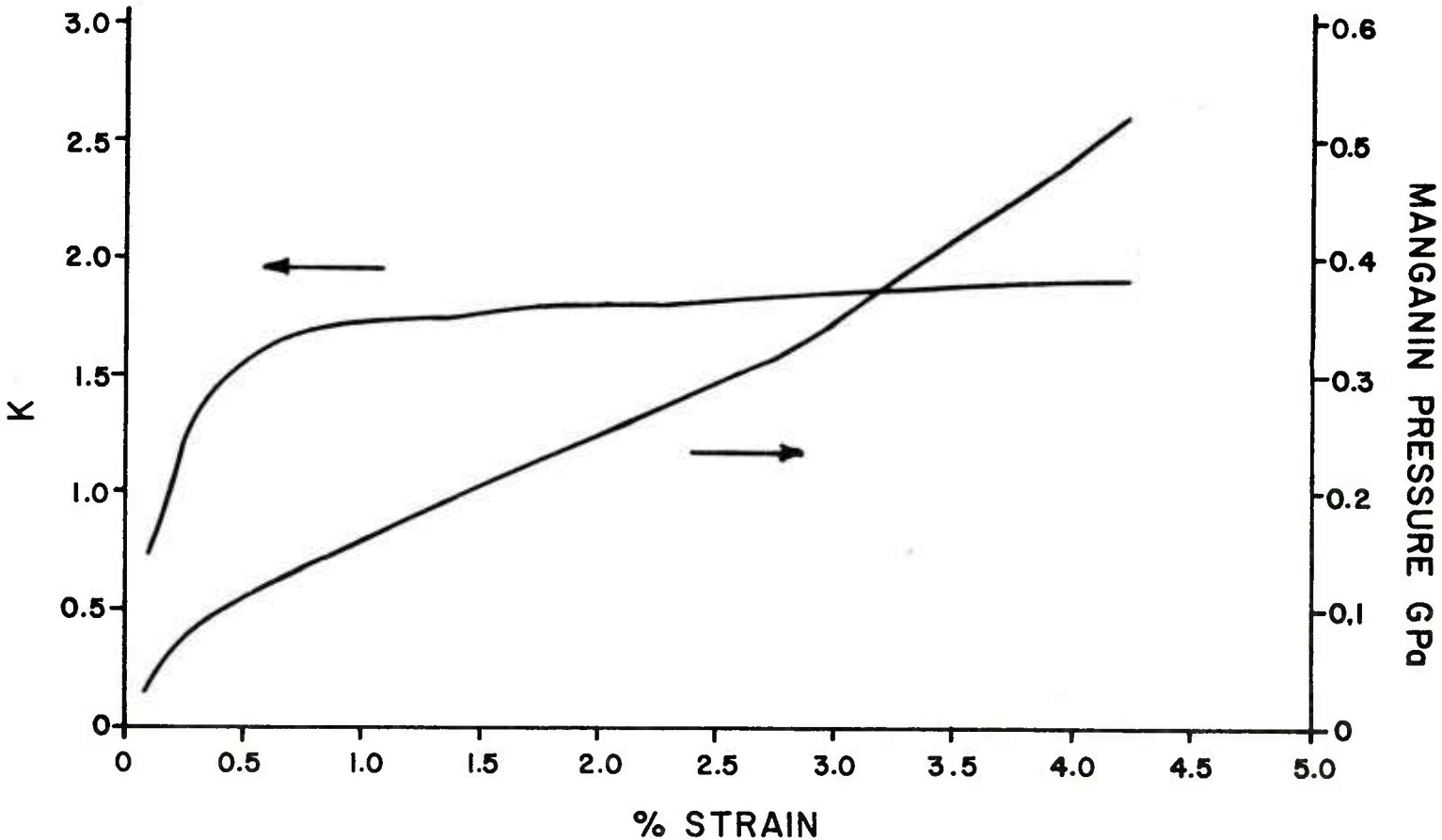

Figure 13. Strain Coefficient (K) of a Manganin Gage as a Function of Strain as Determined in an Activator Test Using a Piston with a 22 mm Radius of Curvature. Pressure versus time is shown on the right hand scale.

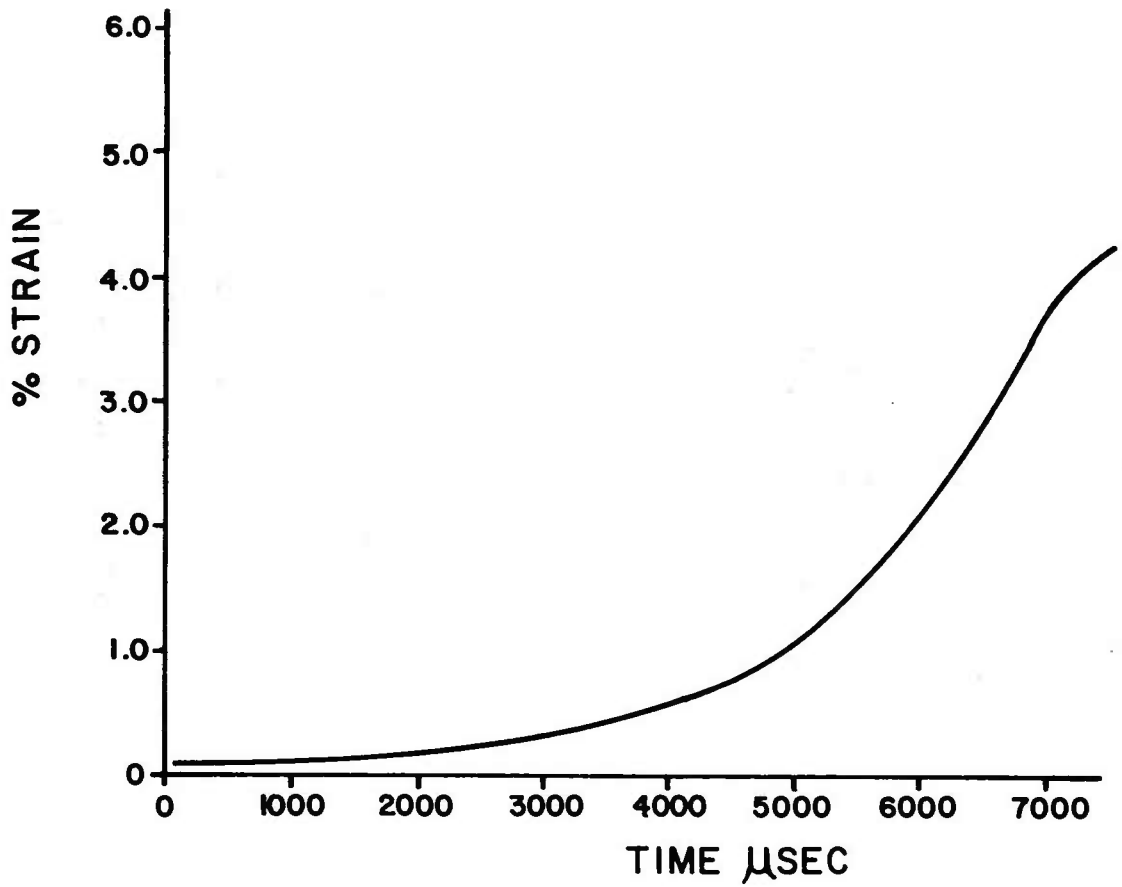

Figure 14. Strain as a Function of Time for the Test Depicted in Figure 13

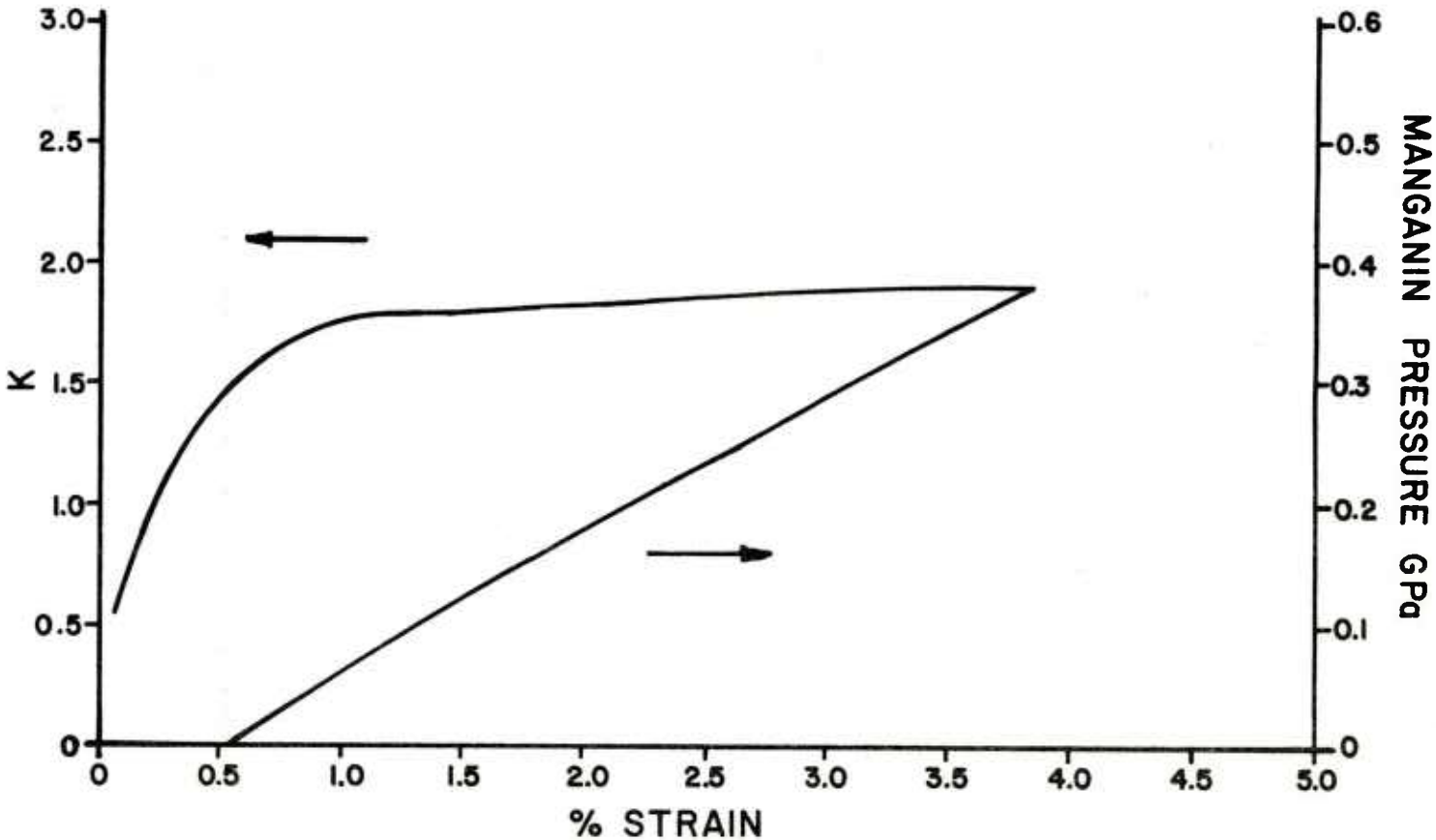

Figure 15. Strain Coefficient (K) of a Manganin Gage as a Function of Strain as Determined in an Activator Test Using a Piston with a 22 mm Radius of Curvature and Unprecompressed Cerrobend Pressure Transfer Disc. Pressure versus time is shown on the right hand scale.

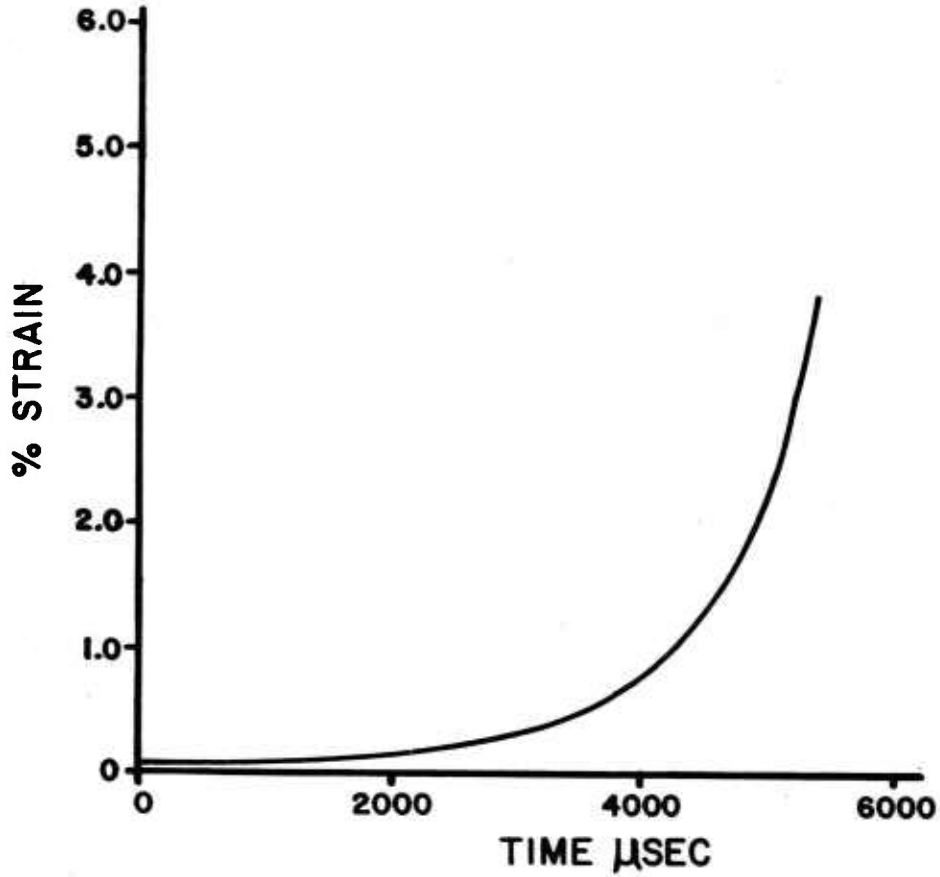

Figure 16. Strain as a Function of Time for the Test Depicted in Figure 15

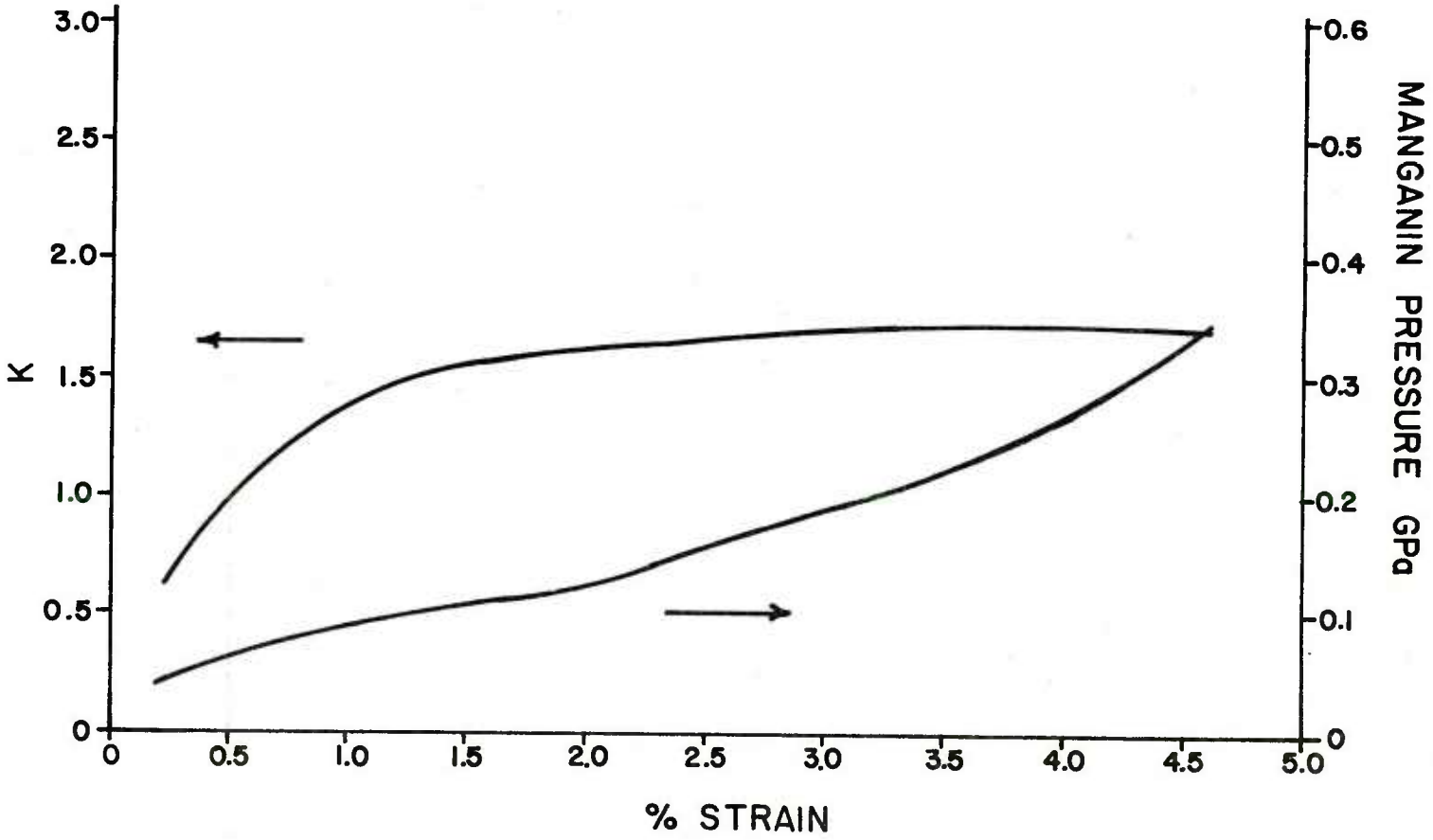

Figure 17. Strain Coefficient (K) of a Manganin Gage as a Function of Strain as Determined in an Activator Test Using a 3 mm Gage and a Piston with a 19 mm Radius of Curvature. Pressure is shown on the right hand scale.

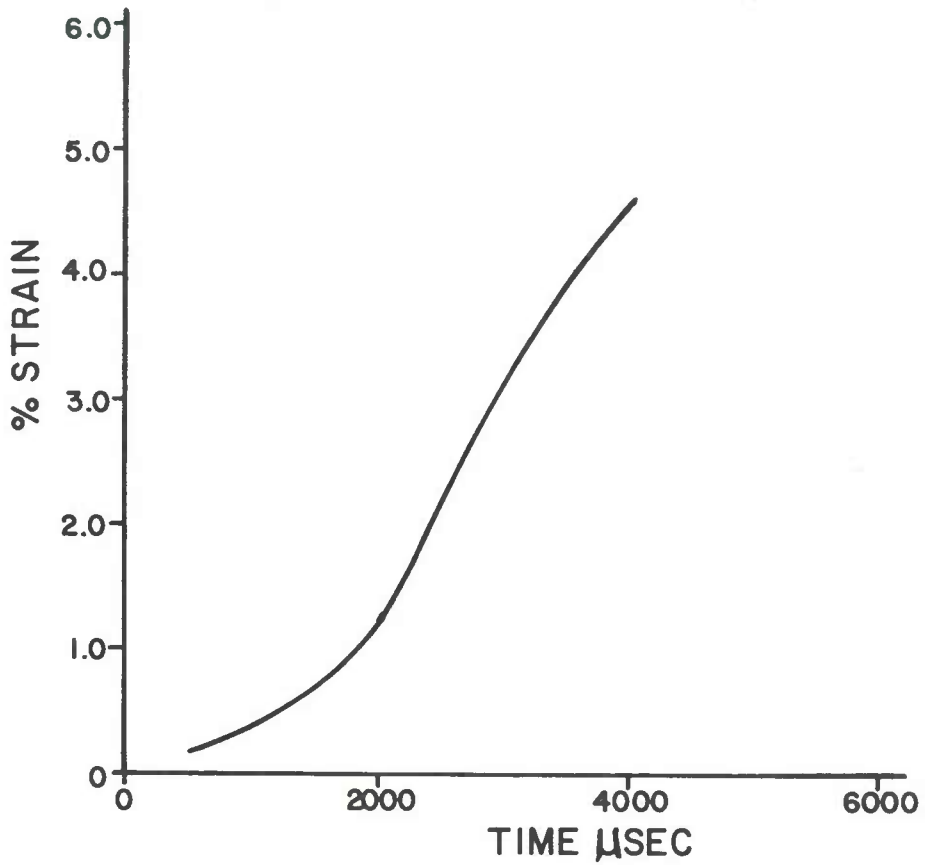

Figure 18. Strain as a Function of Time for the Test Depicted in Figure 17.

$$R = \frac{\rho \ell}{A} ;$$

where R is resistance, ρ is resistivity, ℓ is the length of the gage and A is the cross sectional area. Differentiating and assuming that resistivity and volume (the product of ℓ and A) are constant, gives the following relation:

$$\frac{dR}{R} = 2 \frac{d\ell}{\ell} ,$$

which implies that the strain coefficient should be 2. The constant volume assumption should be valid when the gage is straining plastically, but it is not valid in the elastic regime. Data provided by Mirco-Measurements, Inc indicate that the elastic limit of manganin occurs at about 0.2 percent strain. Mixed elastic-plastic behavior probably extends to higher strains, but it is reasonable to expect that the constant volume assumption will hold for large strains. In the elastic region, resistivity varies because the interatomic spacing is changing. In the plastic region, interatomic spacing should be constant, but resistivity may still change due to the formation of imperfections in the metal. However, it is reasonable to suppose that resistivity will reach a constant value for large strains, and for large strains the strain coefficient should approach the value of 2.

In the cantilever beam tests, the strain coefficient approached 2 at about 2 percent strain. In the activator tests with 6.4 mm gages, the transition was more rapid, and the strain coefficient reached a value of 1.8 at about 0.5 percent strain and increased slowly after that. A single activator test with a 3.2 mm gage looked more like the cantilever beam tests. It appears that a strain coefficient of 2 is reasonable for experiments where the strain is 2 percent or greater. Between 0.1 and 2.0 percent strain, there is an uncertainty in the value which should be used. We have not been able to explain the variation in the data between 0.1 and 2.0 percent strain in terms of pressure or strain rate, but our data is not sufficient to draw any firm conclusions in this regard. It is tempting to ascribe the more rapid rise of the strain coefficient in the activator experiments to the higher pressure in these experiments. All of our data are consistent with the observation that when strain is greater than 0.5 percent and pressure is greater than 0.1 GPa. The strain coefficient is between 1.8 and 2.0. However, a single activator shot was performed with unprecompressed cerrobend behind the 3.2 mm plate (see Figure 15). In this experiment, considerable strain occurred before there was any significant pressure, but the strain coefficient as a function of strain increased nearly as rapidly as it did in the other activator shots. This indicates that some factor other than pressure may be responsible for the difference between the cantilever beam tests and the activator tests.

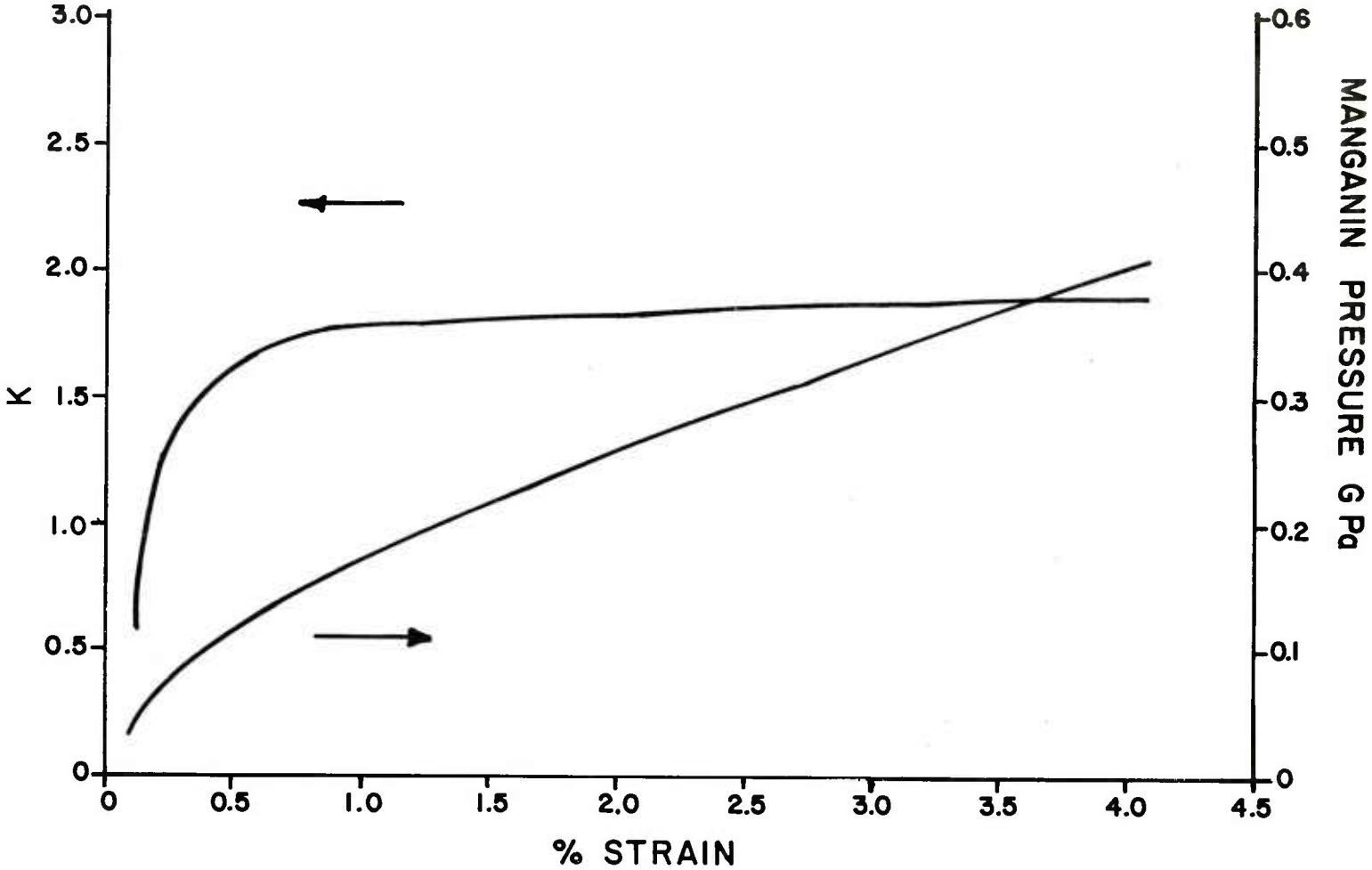

Figure 19. Strain Coefficient (K) of a Manganin Gage as a Function of Strain for the Experiment which gave the Most Rapidly Increasing K Factor

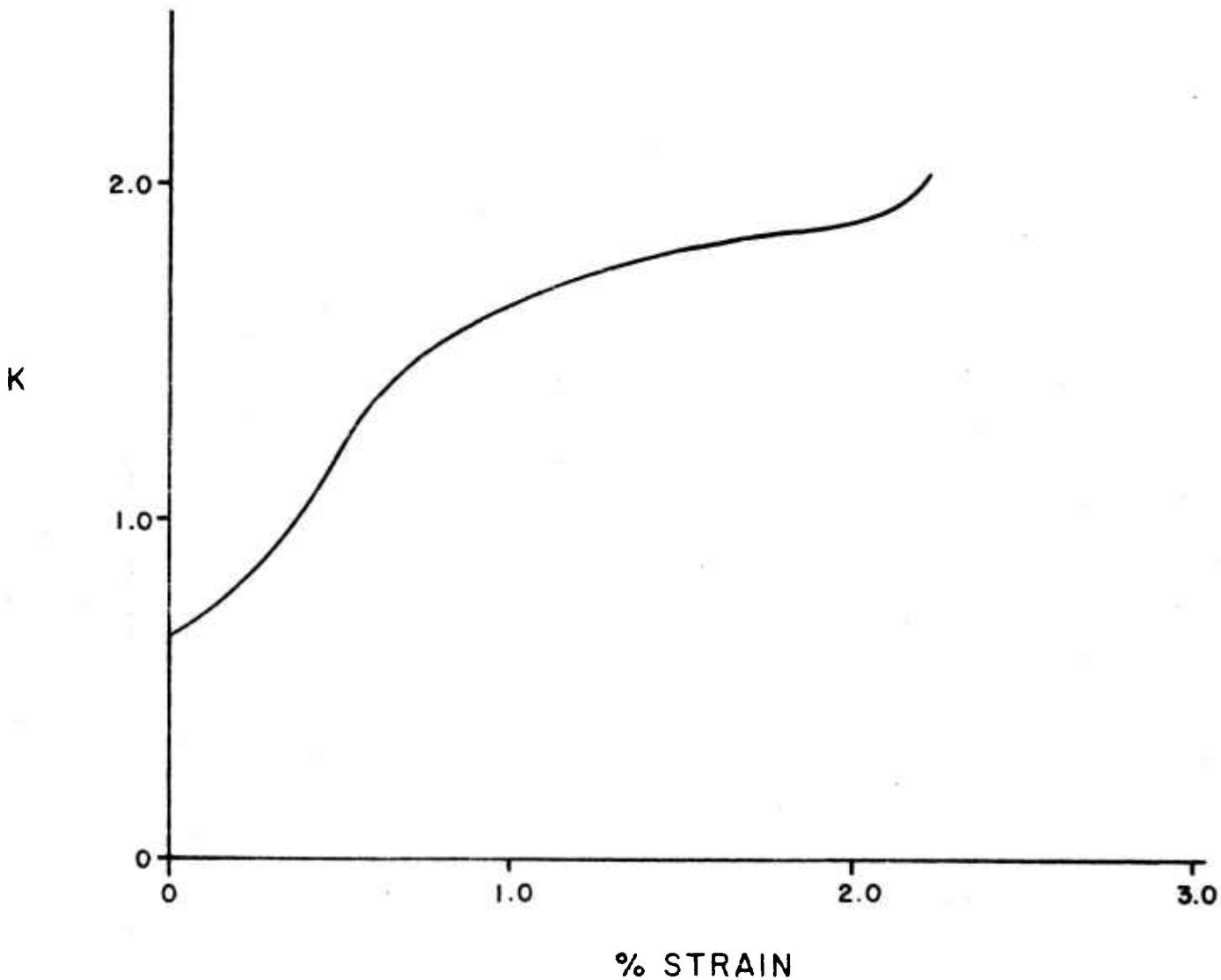

Figure 20. Strain Coefficient (K) of a Manganin Gage as a Function of Strain for the Cantilever Beam Test which gave the Most Slowly Increasing K Factor

V. CONCLUSIONS

The strain coefficient of manganin appears to be about 0.67 for strains which are less than 0.1 percent and 2 for strains above 2 percent. In these regions of strain, the manganin - constantan combination gage appears to be useful. More work is needed to characterize the strain coefficient of manganin between 0.1 percent and 2 percent strain.

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